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DOES WATER FOAM EXIST IN MICROGRAVITY ?

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Liquid foams are omnipresent in everyday life, but little is understood about their properties. On Earth, the liquid rapidly drains out of the foam because of gravity, leading to rupture of the thin liquid films between bubbles. Several questions arise: are liquid foams more stable in microgravity environments? Can pure liquids, such as water, form stable foams in microgravity whereas they do not on Earth? In order to answer these questions, we performed experiments both in parabolic flights and in the International Space Station.



Liquid foams [1] consist of gas bubbles dispersed in a liquid and stabilised by surface-active species, such as surfactants, proteins, polymers or particles. The internal structure of liquid foams – formed by the complex network of gas/liquid interfaces – leads to extremely interesting physical properties. For instance, liquid foams are soft solids and melt under the action of small forces. This is why shaving foam sticks to the face but conveniently flows under the razor blade. Foams are also strong scatterers of light and sound, which leads to remarkable optical and acoustic properties. They play important roles in detergency (shampoo, dishwashers), provide important texture properties to food (whipped cream, chocolate mousse, bread) and additional sensorial aspects to drinks (cappuccino, beer). They help extracting crude oil (oil recovery), refining minerals (flotation) or extinguishing fires.

On the other hand, many applications struggle with unwanted foams (just think of the paper and paint industry) or need to maintain the foaming properties at a

well-controlled level (washing powders), so that suitable “antifoams” need to be designed. Last but not least, most solid foams are made from liquid precursor foams. Solid foams, despite being light, are very resistant mechanically (metallic foams for cars) and are exceptionally good insulators for heat and sound (polymer foams). As a consequence of their remarkable properties, foams are omnipresent in everyday life. Despite this abundance in applications of foam, little is understood yet about their properties. In particular their stability remains mysterious: the simple question of why a soap bubble bursts is still waiting for a clear explanation [2]. As a result, empiricism is currently employed to estimate the operational window and design for foam handling in industrial processes.

Studying foam

The main difficulty of foam studies arises because they are short-lived in general. Foams are metastable systems and their formation requires energy in order to create new interfaces between liquid and gas phases: an increase in surface area of ΔA corresponds to a surface energy of $\gamma \Delta A$, with γ the surface tension. The foam then evolves with time in order to decrease this surface energy via two independent processes: *coalescence*, which is the rupture of films between bubbles, and *coarsening*, which is gas transfer between the bubbles due to their different internal pressures. Both processes lead to an increase of the bubble radius with time, but they are not easy to distinguish. A third ageing mechanism is the gravity-driven *drainage* of liquid between the bubbles. This removes liquid from the foam and influences both coarsening and coalescence. In order to disentangle the different effects, one should ideally suppress drainage. Performing experiments in microgravity is a unique way to study foams containing a substantial amount of liquid. Indeed, obtaining stable foams with large liquid fraction ϕ ($\phi > 20\%$) on Earth is impossible; various hydrodynamic instabilities even accelerate drainage [1].

This prevents the study of very wet foams, formed at the beginning of the foam life and thus an important step in foaming processes. Furthermore, wet foams show a particularly interesting transition when the bubbles are closely packed, but still spherical (Fig. 1). For disordered foams this “jamming transition” occurs at a liquid fraction $\phi^* \approx 36\%$. For smaller ϕ , the bubbles are distorted into polyhedra and the foam behaves like a soft solid. By contrast, at larger ϕ the foam behaves like a viscous liquid since the bubbles are separated by enough liquid

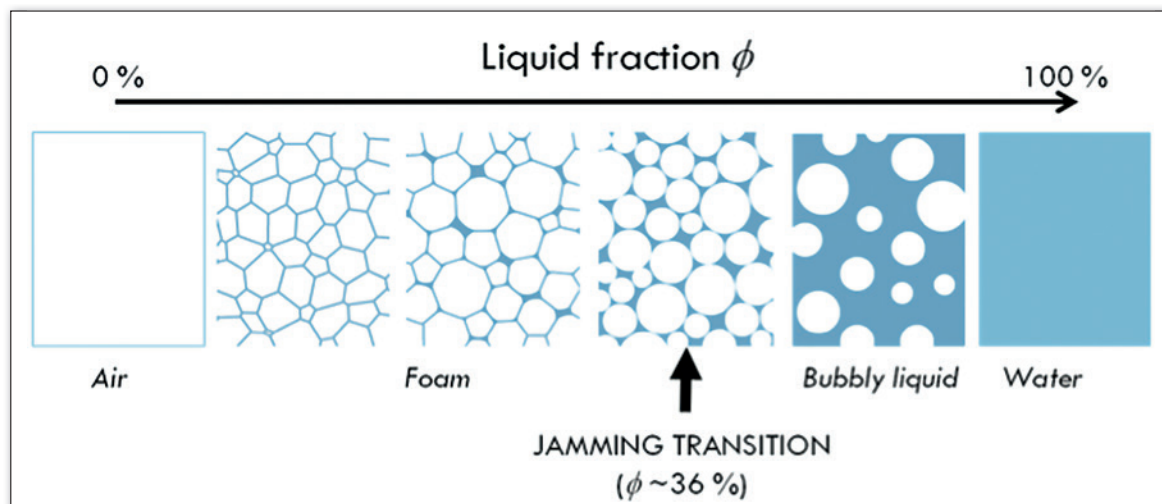


Performing experiments in microgravity is a unique way to study foams containing a substantial amount of liquid



Image courtesy of ESA

► FIG. 1: Scheme of foam evolution upon increasing liquid fraction ϕ . Image courtesy of Wiebke Drenckhan



to move independently. Similar jamming transitions are encountered in other assemblies of randomly packed objects, such as sand, clays, emulsions, *etc.*, which are presently the object of much interest [3].

Microgravity

Many studies of isolated bubbles in microgravity have been reported, in connection to various problems: bubbling [4], boiling [5], two-phase flow [5], electrolysis [6], combustion [7], impinging of jets [8]. However, microgravity experiments on foams are still scarce despite the promises they hold for scientists. Various foam experiments are in preparation for the Fluid Science Laboratory of the ISS, supported by the European Space agency (ESA) [9]. As part of the preparations, we benefited from opportunities offered by educational programs of ESA to tackle two long-standing questions: can we make stable wet foams in microgravity? And do pure liquids foam in these conditions? For this purpose, simple foaming experiments were performed on parabolic flight campaigns (PFC) which simulate microgravity during 15 s, and by astronauts in the ISS (Fig. 2) [10].

They showed that wet foams containing surface active agents were stable in microgravity [10].

Pure water

In this article we present results on foams made with pure water. We used three different mechanical systems for the foam production under micro-gravity conditions. In the first device, the liquid and air are rapidly pushed back and forth through a constriction between two syringes. In the second device, a porous plate moves back and forth in a cylinder containing liquid (the “mighty whipper”). The third device is the simplest to operate and was designed for use in the ISS: a heavy bead is shaken in a cylinder containing both air and liquid, in order to incorporate bubbles in the liquid. Earth-based experiments have been performed using the same foaming devices for comparison with normal gravity conditions.

Water studies in parabolic flights and aboard the ISS are fully consistent. The PFC foaming devices allowed creating foams with various liquid fractions. In the ISS less gas could be incorporated in the liquid because the energy involved in the mixing procedure was much lower; as a consequence, the liquid volume fraction remained large.

Are water foams stable?

Once formed, the bubbles remained stable over long periods of time in microgravity conditions. They may move somewhat, but not enough to coalesce (Fig. 3, left). This is due to the absence of drainage: bubbles stay sufficiently far apart, avoiding coalescence. On Earth and in the same conditions, water does not contain any bubbles (Fig. 3, right).

Foams close to the jamming transition

First of all and in line with earlier observations [10], solutions that are difficult to foam on Earth also require more vigorous shaking in microgravity, and water is no exception.

Pictures of foams made with a liquid/air volume ratio of 30% are shown in Fig. 4. One sees that the “mighty whipper” is the most efficient device: the bubbles are smaller and less polydisperse (sizes between 100 and 500 μm). With the two-syringe and bead-cylinder devices the range of sizes is wider (100 μm -1 cm).

▼ FIG. 2: Astronaut Frank de Winne with the foam cells in the ISS; a cell rack is free floating in the centre of the picture and a second rack is placed in front of a computer screen for backlight illumination during video recording. Image courtesy of ESA.



More surprisingly, it is not possible to generate a foam with $\phi < \phi^*$. Even with initial liquid/air ratio of 20 and 30%, we ended up with a dispersion of packed bubbles because we could not incorporate all the air into the liquid (Fig. 3). Only the most efficient mixing device (mighty whipper) produced foams with ϕ close to ϕ^* , although never smaller. Fast-coalescence events were observed as soon as the bubbles came close to each other whereas such events are absent in the bubbly state ($\phi > \phi^*$).

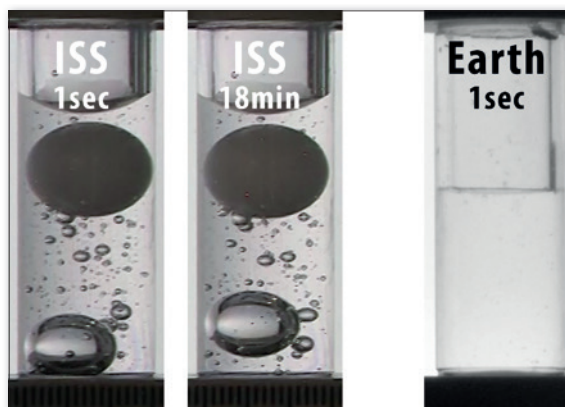
Why are foams with $\phi < \phi^*$ disappearing rapidly, as they do on Earth? We propose the following explanation: when $\phi < \phi^*$, the bubbles are distorted and films form (Fig. 1). These films are thin because of capillary suction into film borders, despite the absence of gravity drainage, as demonstrated in earlier PFCs [11]. Thinning of pure water films is extremely fast and bubbles coalesce fractions of seconds after getting into contact. Indeed, the surface energy $\gamma\Delta A$ is decreased in this process, because the area is decreased.

In summary, we showed that water foam with spherical bubbles is stable in microgravity, even in dense systems close to the jamming limit ($\phi > \phi^*$). Below this limit, the bubbles are distorted into polyhedral shapes. Films form between bubbles, they get thin rapidly due to capillary-driven drainage, followed by film rupture, as on Earth. As a result, stable foam with *polyhedral bubbles* is not formed from pure water, even in microgravity.

Apart from the scientific side, these findings are also of interest for the handling of fluids in microgravity environments. Further more elaborate experiments are planned in the Fluid Science Laboratory of the ISS in 2016. ■

Acknowledgements

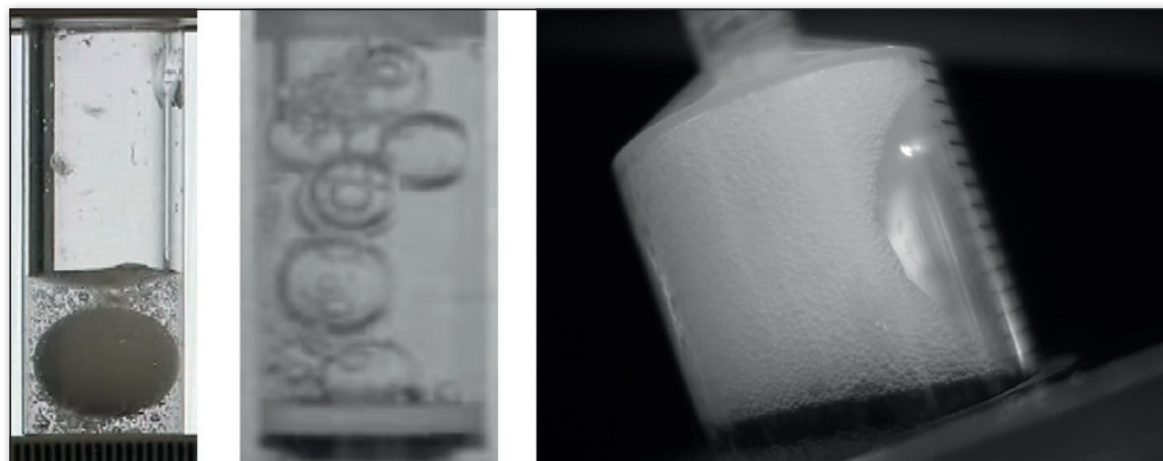
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◀ FIG. 3. Left: water samples made in the ISS, 1 second and 18 minutes after shaking. Right: Pure water on Earth, 1 second after shaking in the same conditions

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◀ FIG. 4: Pure water foams made in microgravity with liquid/air volume ratio of 30%; Left: ISS, bead-cylinder device. Middle: PFC, two-syringe system. Right: PFC, mighty whipper.